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Review article

Carbon felt based-electrodes for energy and environmental applications: A review

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ABSTRACT

Carbonaceous materials are abundantly used for electrochemical applications and especially for energy and environmental purposes. In this review, the carbon felt (CF) based-electrodes are discussed in a holistic manner. First of all, the study centers on the issues relevant to pristine CF materials such as manufacturing method and specific properties. The various methods and equations used to identify physical values of CF material are supplied. As main part of the review, the different modification methods for CF electrodes are described. The novel properties of fabricated materials are characterized by physical as well as electrochemical techniques. The strengths of each method are presented in the comparison with raw CF electrodes. The energy applications of CF based-electrodes are figured out in various fields such as vanadium redox flow batteries (VRFB), microbial fuel cells (MFCs), biofuel cells (BFCs), capacitors, solar cells and lithium ion batteries. For environmental applications, we focus our study on the wastewater treatment containing biorefractory pollutants by electro-Fenton (EF) process. The degradation result by EF technology using CF materials is impressive when most of toxic contaminants are mineralized to non-toxic compounds at the end of the electrolysis. To decrease the cost treatment and upgrade the treatment efficiency, the EF system has been improved by using modified electrodes or new catalyst sources. The CF materials are also investigated to apply in bio-fuel cell-Fenton in which electrons were produced from fuel cell (FC) towards zero-energy depollution. Finally, the sketches about EF pilot open new gates for application of CF materials in industrial areas.

Contents

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1. Introduction

Carbon Felt (CF) is commonly used as electrodes due to their good electronic conduction. They have high surface area and porosity able to provide abundant redox reaction sites, excellent electrolytic efficiency and mechanical stability at relatively low cost [1–4]. Other carbon-based materials like vitreous carbon, carbon sponge, carbon fiber or carbon paper have been also applied widely for electrode application. However, these materials show some limitations in comparison with CF. For example, it is impossible to manufacture a cheap electrode with vitreous carbon due to its expensive price. Carbon paper would not be a perfect choice for tubular electrode because of its rigid properties. Toward an electrode commercially available with a low price and present tenacious and stable properties, CF has been chosen as the best candidate in this review. They simultaneously have, however, some disadvantages relevant to their inadequate wettability and electrochemical activity in aqueous solutions because of their hydrophobic surface nature and poor kinetics for reduction and oxidation reactions. This partly declines the performance of pristine CF when it is applied at electrodes [5,6]. In the effort to make the CF electrodes more active, several modification methods have been adopted at various conditions. After modification process, the electrochemical activity of CF could be remarkably enhanced [6,7].

CF based-electrodes have been the subject of few reviews relevant to energy and environmental topics. Most reviews focus on redox flow batteries (RFBs) and wastewater treatment by electrochemical advanced oxidation processes (EAOPs). Chakrabarti et al. reported some modification methods to improve the catalytic properties and the conductivity of CF electrodes for RFBs such as deposition of metals, addition of functional groups by chemical and thermal treatments on the electrode surface. Several methods to produce vapor grown carbon fibers, carbon nanotubes (CNTs), or nitrogenous groups on the carbon fiber surface of graphite felt (GF) electrodes were discussed [8]. The progress on felt electrodes in RFBs was still a fascinating topic in some recent reviews [9,10]. Beside that, CF was used widely as cathode materials for removal of persistent organic pollutants (POPs) in aqueous medium by EF process. According to the review of Brillas et al., carbon electrodes present many advantages like nontoxicity, good stability, conductivity, and chemical resistance [11]. The efficiency of EF system using CF cathodes was summarized in the comparison with other materials like activated carbon fiber, reticulated vitreous carbon, carbon sponge, *etc.* [12–14]. Obviously, reviews dedicated to CF based-electrodes have concentrated only a few of their characteristic features or modification methods towards individual applications. From these reviews, it is actually difficult to understand this material in detail or to choose suitable methods of modification for various demands. The surmount of this difficulty requires deeper reviews focusing on the different aspects of CF materials, which were investigated according to the following scheme:

- First, we discuss the commercial method of producing CF materials and supply the specific properties combining with methods and equations to identify physical values of CF materials.
- The most important part is the modification methods used to improve the properties of CF electrodes relating mainly to hydrophilicity, conductivity, and electroactive activity. Interestingly, the different modification methods induce different performance.
- Both pristine and CF electrodes are applied in energy field of VRFB, MFCs, BFCs, capacitors, electrochemical solar cells and lithium ion batteries. From there, we compare and discuss the upgraded efficiency of modified electrodes.
- Afterward, we concentrated on using CF cathodes for wastewater treatment by EF technology. Unlike the previous reviews about removal POPs by EF technology, this study presented a new approach with following structure: First, we present the definition about EF process and the studies using non-modified CF cathode. In the next step, we investigated the modified EF systems on the basis of various aspects: configuration, cathode material, and catalyst. Beside that, we looked at bio-Fenton systems without input power in which clean and green energy from FC is used for EF process. Finally, with an eye towards industrial applications, some EF pilot scales were investigated for the treatment of a large volume of pollutants solution. Using solar radiation as available power for EF pre-pilot plants is also